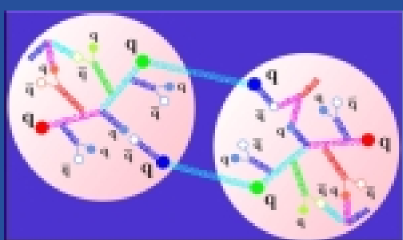
Office of Science

U.S. Department of Energy

# Nuclear Physics

The Office of Science's Nuclear Physics (NP) program provides most of the Federal support for nuclear physics research in the U.S., delivering new insights into our knowledge of the properties and interactions of atomic nuclei and nuclear matter. About 1,500 scientists, including 800 doctoral students and postdoctoral associates, receive support from NP. In addition, the U.S. plays a world-leading role in fundamental nuclear physics research through NP support of six national scientific user facilities.



*A conceptual sketch of the quark structure of the proton and neutron forming a deuteron*

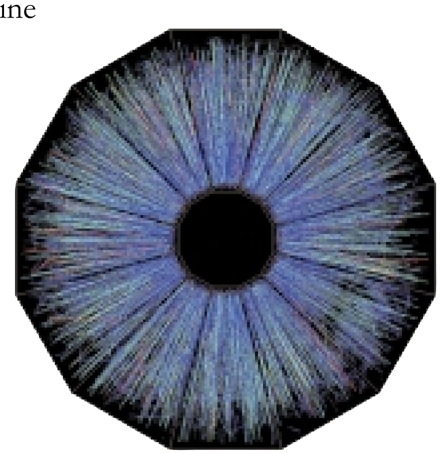
## The Opportunity

The NP program is focused on new and exciting opportunities to investigate the very early universe, measure the quark structure of the proton and neutron, and advance the fundamental theory of matter by studying neutrino oscillations. New technologies provide the experimental and theoretical possibilities to investigate in detail, and for the first time, complex many-body nuclear systems, from the tiny nucleons to stars and supernovae. Rapid recent advances in miniaturization of electronic circuits, vastly increased computer power, and superconducting magnet and radio-frequency accelerator technologies have enabled the construction of new accelerator, detector, and computing facilities that now allow us to pursue these opportunities.

## The Challenge

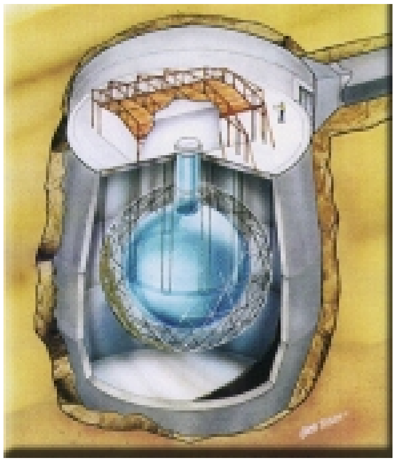
NP's research focuses on understanding the early universe and describing how the fundamental building blocks of matter interact. We accomplish these goals through research programs that examine the following challenge:

**The Early Universe.** How did the early universe evolve right after the Big Bang, creating nuclear matter from energy? A unique new research facility, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, collides beams of gold nuclei at energies sufficient to form brief glimpses of the extremely hot and dense plasma of free quarks and gluons that existed only for the first microseconds after the Big Bang. Our first physics results were obtained in 2000; today a full experimental and theoretical program is underway to study this new state of matter.



*Thousands of particles emerge from a collision of gold nuclei at RHIC*

**Structure of the Nucleon.** How do the basic quark "building blocks" bind together with gluons to form the proton and neutron, the nucleons that make up nuclei, and how do we account for the nucleon spin? The quarks alone make up only 2% of the mass and generate only about 25% of the intrinsic spin. The Thomas Jefferson National Accelerator Facility (TJNAF), the premier facility of its kind in the world, provides an intense polarized electron beam to study nucleon structure. The experimental results are now beginning to address these fundamental questions.



*The Sudbury Neutrino Observatory in its underground cavern*

**Neutrinos.** What are the basic properties of neutrinos? The first generation of solar neutrino experiments detected fewer high-energy neutrinos than expected from our knowledge of nuclear processes in the Sun, and suggested that neutrinos may change from one type to another, a property that is not part of the Standard Model of elementary particles. The new Sudbury Neutrino Observatory (SNO) experiment in Canada, a collaborative project of Canada, the U.K., and the U.S., is studying solar neutrinos with much greater precision than previously possible. In 2001, first results from SNO, when combined with data from the Super-Kamiokande experiment in Japan, indicated that solar neutrinos do change types en route to Earth, adding compelling evidence that neutrinos have mass. This mass would contribute to the dark matter that makes up most of the universe.

*An exploding nebula*

**Origin of the Elements.** What is the origin of the elements, how do stars evolve, and what is the source of high-energy cosmic rays and cosmic gamma rays? Experiments are now being carried out with beams of stable and short-lived nuclei at accelerator facilities at the Office of Science's Oak Ridge, Argonne and Lawrence Berkeley national laboratories to measure the properties of nuclei and reaction rates needed to decipher the full range of astrophysical optical, x-ray, and gamma-ray data. R&D for a next generation accelerator with far more intense beams of short-lived nuclei is underway, and experimental results from such a facility could have a profound impact on our basic knowledge of nuclear structure and the origin of the elements in stars and stellar explosions.

## Investment Plan

The NP program's goal is to provide significant support for its major user facilities, allowing them to develop their full potential through expanded use by researchers worldwide. Support for theoretical studies will be enhanced through the development of new computational techniques and advanced simulations, in conjunction with another Office of Science program, Scientific Discovery through Advanced Computing (SciDAC).

## The Benefits

The Office of Science's Nuclear Physics program will maintain the leading role of the U.S. in nuclear physics, which has been central to the development of various technologies including nuclear energy, nuclear medicine, and the nuclear stockpile. Highly trained manpower in fundamental nuclear physics continues to be essential for many applied fields, such as nuclear medicine, medical physics, space exploration, and national security.

*Thomas Jefferson National Accelerator Facility seen from the air*

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